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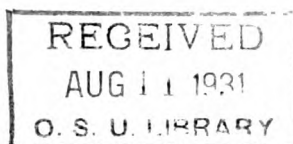
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**TUNNEL DRIVING METHODS USED AT THE OJUELA UNIT  
OF THE COMPANIA MINERA DE PENOLES, S. A.,  
OJUELA, DURANGO, MEXICO**



**BY**

**JOHN P. SAVAGE**

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TUNNEL DRIVING METHODS USED AT THE OJUELA UNIT

OF THE COMPANIA MINERA DE PENOLES, S. A.,

OJUELA, DURANGO, MEXICO<sup>1</sup>

By John P. Savage<sup>2</sup>

INTRODUCTION

This paper is one of a series being prepared by the United States Bureau of Mines on tunneling methods. The tunneling methods described are those used at the Ojuela unit of the Compania Minera de Penoles, S. A., the Mexican subsidiary of the American Metal Co., Ltd., of New York.

The Ojuela unit is situated some 4 miles southeast of Mapimi, Durango, Mexico, the latter place being connected by a 15-mile narrow-gage railway with the standard gage railroad at Bermejillo, some 40 miles to the north of Torreon, the location of one of the company's smelters.

The Ojuela mine has been working for some three hundred years and is one of the largest in point of extent of underground workings in the Republic. It is a lead-silver mine and is producing about 8,000 tons of ore per month.

ACKNOWLEDGMENTS

This paper is a combination and rearrangement of two articles, one by John W. Beard published in the Engineering and Mining Journal,<sup>3</sup> and the other by George W. Hezzelwood for the Explosives engineer.<sup>4</sup> R. G. Bloomer, engineer of the tunnel, materially aided in the compilation of this article.

PURPOSE AND BRIEF DESCRIPTION OF PROJECT

In the early part of 1927 an estimate on the probable life of the mine was made and, when completed, plans were formulated to work all sections at the same time and to handle 10,000 gallons of water per minute. The tunnel was to be used only as a water exit to lower the pumping head. Due to the long distance between various underwater sections, centralizing the main pumping plant and taking advantage of present workings were important factors in choosing the location of the tunnel.

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used:  
"Reprinted from U. S. Bureau of Mines Information Circular 6480."

2 Superintendent, Ojuela unit, Compania Minera de Penoles, S. A.

3 Beard, J. W., In an Adit Heading at Ojuela Averaging 714 Feet per Month for 5,000 Feet: Engineering and Mining Journal, July 14, 1928, pp. 46-51.

4 Hezzelwood, G. W., Drilling and Blasting at the Ojuela Drainage Tunnel: Explosives Engineer, November, 1928, pp. 413-416.

The final project called for a 9 by 8½ foot tunnel, without ditch, 5,407 feet long with an open cut of 616 feet outside the portal. The gradient of the tunnel was 0.3 per cent. A 328-foot raise was driven from level 12 to connect with the tunnel. As it was estimated that the annual saving would be around \$100,000, speed was of prime importance.

An average advance of 714 feet per month was maintained throughout the seven full months of machine operation. This, we believe, has set a new record for average monthly footage in a tunnel of this size. Furthermore, all work was done with native labor on day's pay, with the exception of the tunnel superintendent, three shift bosses, and engineer, who were Americans.

## GEOLOGY

The properties of the Ojuela unit are located on or near a prominent mountain of limestone called "La Bufa." This mountain is made up chiefly of a series of limestones, with two minor beds of shale. The general form is that of a dome, from the center of which the strata dip away into the plain (fig. 1).

The opencut and first 300 feet from the portal of the tunnel consisted of caliche and soil. The next 2,300 feet passed through calcareous shales which were cut by several diorite dikes varying in thickness from 10 to 80 feet. The center or next 1,500 feet went through a small anticline of limestone. This was followed by 950 feet of black calcareous shales. The remainder of the tunnel and the raise were in limestone.

## PRELIMINARY SURVEYS

Preliminary surveys demonstrated that a 328-foot raise at the east end of the San Jorge crosscut would give the height necessary to accommodate the gradient of the adit, which would be 6,018 feet in length.

Two different survey parties were used, each employing different methods in so far as possible to determine the alignment. One survey was made entirely by transit and tape traverse. The other party did the surface work by triangulation. The tie between surface and underground workings was made by hanging one wire in each of two shafts, which were 2,340 feet apart. The plumbing and traverse between the wires was done separately by each party.

Due to the importance of the resultant grade line, the leveling was naturally given particular attention.

The adit holed through upon the breaking of the round calculated to connect. The alignment was found to be out 0.8 foot and the elevation 0.25 foot. Credit for this good work is due to R. G. Bloomer, A. L. Ferris, R. Rhew, Henry Holcombe, and Francisco L. G. Quintanilla.

## TUNNEL OPERATIONS

### Preparation Period

Due to the distance of the portal from the mine it was necessary to build a camp to house the workmen and equipment. All buildings were of galvanized iron over wooden frames. The following buildings were constructed:

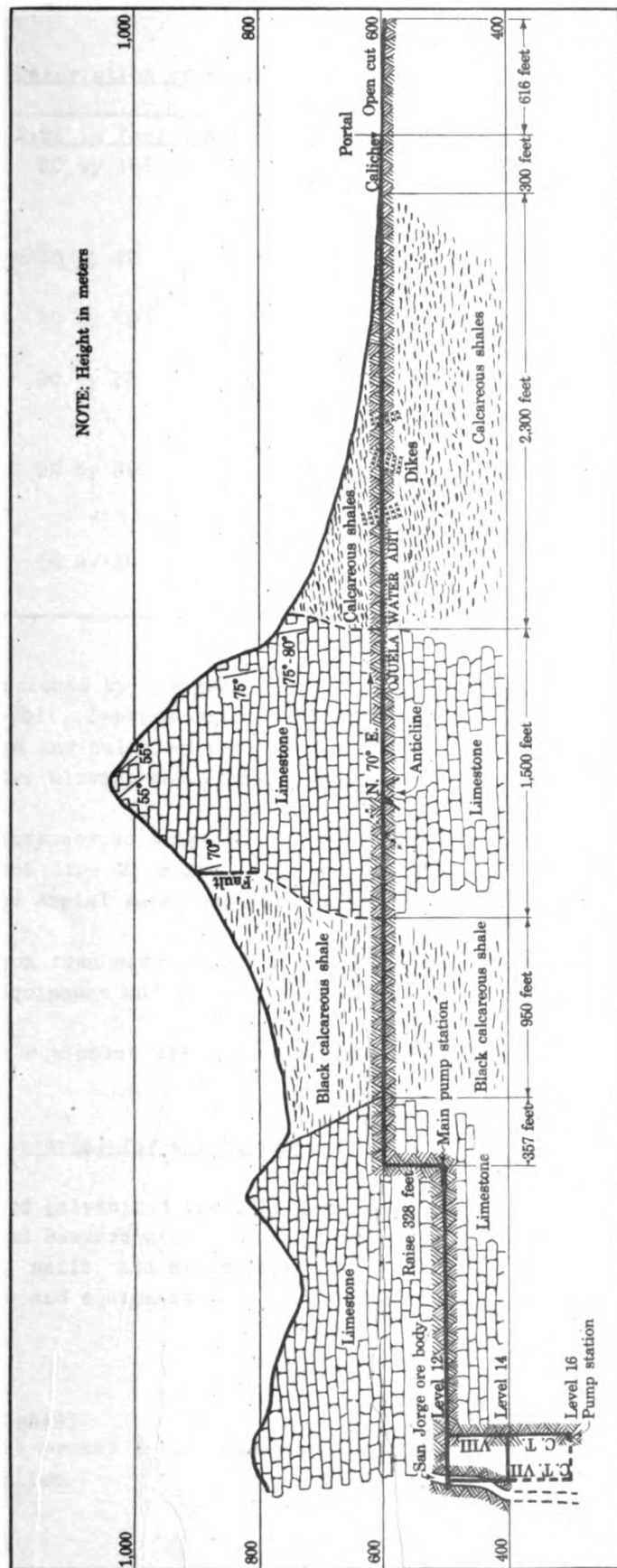


Figure 1.-Section through Ojuela water adit showing connection with northern portion of mines

Description of buildings at the Ojuela Unit

| Name                 | Size in feet | Number of rooms | Details                                                                                                |
|----------------------|--------------|-----------------|--------------------------------------------------------------------------------------------------------|
| Workmen's barracks   | 20 by 158    | 32 10 by 10     | Unfloored, unlined, lean-to roof, one door to each room. Equipped with shower bath.                    |
| Office and warehouse | 20 by 20     | 4 10 by 10      | One-half floored, unlined, lean-to roof, windows, and doors.                                           |
| Shop                 | 20 by 26     | 1               | Unfloored, unlined, gable roof on trusses, windows and doors.                                          |
| Compressor house     | 20 by 33     | 1               | Floored, unlined, gable roof on trusses, windows, doors, lean-to addition for blower-motor and belt    |
| Boarding house       | 20 by 39     | 8 10 by 10      | Floored, lined with Beaverboard, gable roof, including 5 bedrooms, bathroom, kitchen, and dining room. |
| Powder magazine      | 16 by 16     | 1               | Adobe, iron roof, floored, no windows, one door.                                                       |

Power was furnished by the construction of a  $1\frac{1}{4}$ -mile line, No. 6 wire on wooden poles, from the 6,600-volt, 3-phase, mine transmission line. Two 200-kv.a. transformers with lightning arresters and switches were borrowed from the mine to step this down to 440 volts for the compressor, blower, and lighting system.

Water for compressor cooling and sanitary use was brought from the mine pump discharge ditch in a 2-inch line  $2\frac{1}{4}$  miles long (with a 400-foot fall). Drinking water was hauled by truck from the Mapimi water system, 4 miles away.

A  $2\frac{1}{4}$ -mile wagon road was cleaned across the plain to the Mapimi-Bermejillo wagon road, to bring in the equipment and for truck service.

The following equipment was purchased which could not be obtained from the mine warehouses:

Construction material for all buildings:

Corrugated galvanized iron, 24 gage.  
Lumber and Beaverboard.  
Hardware, nails, and millwork.  
Furniture and equipment.

Machinery:Shop equipment:

Drill press, anvil, emery wheel, line shaft, motor, sharpener, forge, supplies.

Compressor, I. R., 21 by 12½ by 14 inches, PRE-2, direct-connected to 440-volt, Unity P.F., synchronous motor.

1 - No. 7 Connersville blower.

2 - Vano - S. P.-350, air drive exhausters, 16 inch.

2 - Butler mechanical shovels.

12 - 40 cubic foot, double side dump, roller bearing cars.

1 - 1-ton Ford truck.

Columns, arms, and clamps for drill carriage.

Drills, hoses, and equipment:

8 - N-72 drifters.

1 - R-72 drifter. Trial shipment.

2 - T-3 drifters. Trial shipment.

Track and Track Material:

1,100 second-hand, 20-pound rails with steel ties, new bolts, fish plates and turnouts.

Pipe:

5,900 feet 1-inch black standard for water line.

10,900 feet 2-inch black standard for water supply.

1,100 feet 3-inch black standard for air line.

4,100 feet 4-inch black standard for air line.

5,000 feet 16-inch galvanized ventilating pipe, 16 gage, compression band

joints, 16-foot lengths.

Wire:

27,000 feet No. 6 hard drawn copper wire for power transmission line.

**TUNNEL DRIVING PERIOD**

The size of the tunnel was 9 by 8½ feet. The work was carried on continuously, one shift relieving the other at the face. The shift consisted of the following:

1 shift boss,  
1 drill carriage boss,  
4 machine men,  
4 chuck tenders,  
1 trackman  
4 track helpers,  
1 motorman,  
1 motorman helper.

After considerable experimenting a round was standardized, using 28 holes with double pyramid cut, the cut holes having a depth of 10 feet and the others of 8 feet (fig. 2). Each top machine of the drill carriage drilled eight holes from two settings and each bottom drill put in six holes. Where ground permitted, holes 27 and 28 were omitted. All

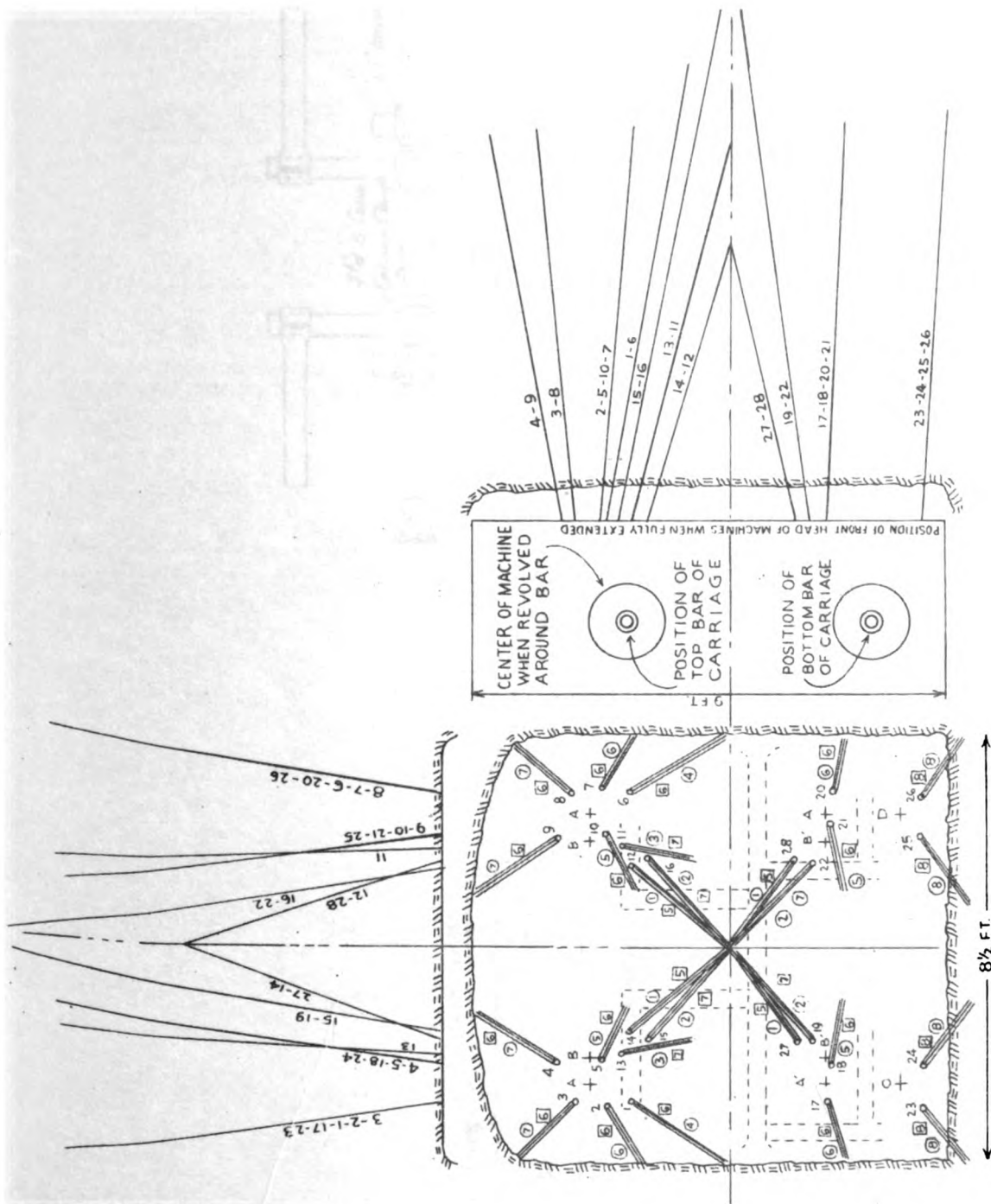


Figure 2.—Standard 28-hole round. Circled numbers indicate order of firing; boxed figures show the number of 40 per cent dynamite cartridges used

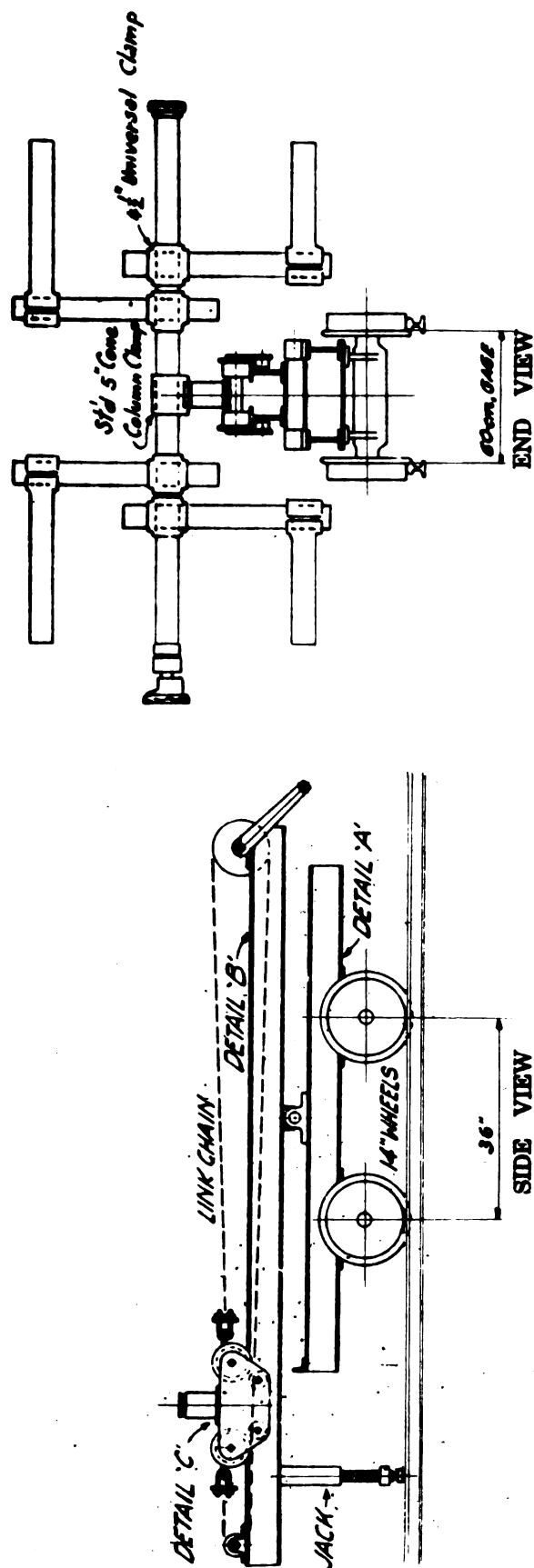


Figure 3.- Drill carriage

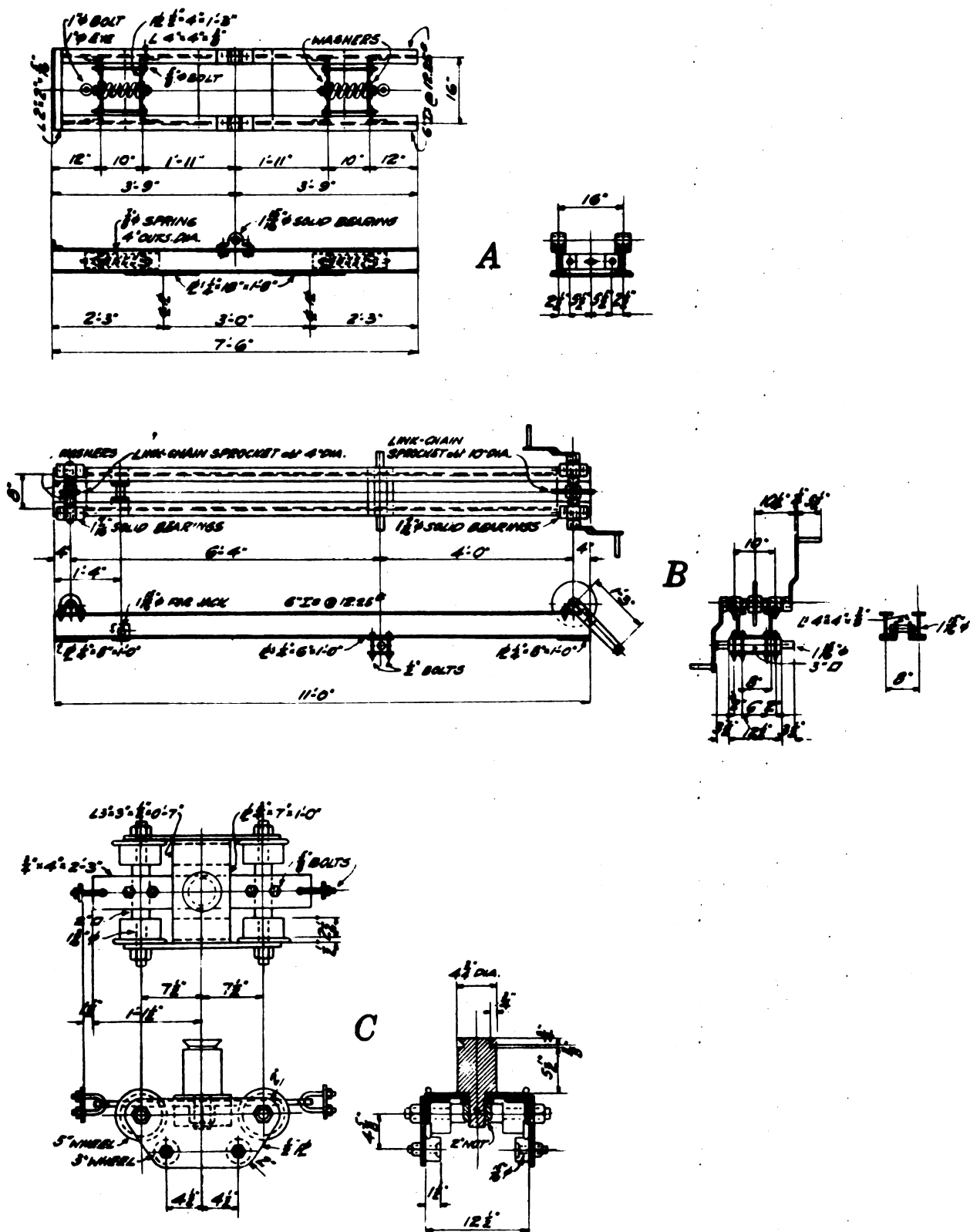


Figure 4.—Details A, B, and C of drill carriage, Figure 3

holes were so spaced that after the cut had been fired, no charge carried more than  $2\frac{1}{2}$  feet of burden. The average length of round pulled was 8 feet. The average cycle for the complete operation of drilling, blasting, and mucking was 5 hours 37 minutes, or 4.27 cycles per 24 hours.

The types of drills used were Ingersoll-Rand N-72 and R-72 drifters and Sullivan T-3 drifters. A specially designed drill carriage (figs. 3 and 4) carrying four machines was used. The steel used was  $1\frac{1}{4}$ -inch hollow round with standard 4-point double taper ( $14$  and  $5^\circ$ ) bits, 10-foot sets with changes of  $2\frac{1}{2}$  feet. The bits were of 2,  $1\frac{1}{8}$ ,  $1\frac{1}{4}$ , and  $1\frac{1}{2}$  inch sizes. The ground was not hard and the steel could be used several times. One man and helper did all the sharpening and other necessary blacksmith work. A special drill tender was designed by Hezzelwood (fig. 5). The tender was designed to eliminate delays in connecting air and water lines and handling steel. The air line was 4-inch and water line 1-inch black standard pipe. They were carried on the floor within a short distance of the face and attached to the Hezzelwood tender by a 3-inch air hose and a 1-inch water hose. Air pressure at the compressor was maintained at 100 pounds, the pressure at the face averaging about 90 pounds.

#### LOADING AND HAULAGE

After the compressor was started, all loading was done by an air-operated Nordberg Butler underground shovel, Model No. 109. This shovel handled the muck at the rate of 34 tons per hour.

The track was 23-inch gage, of 20-pound rail, on steel ties spaced at 3 feet, fish plates being used at rail joints. A portable Hezzelwood switch (fig. 6) was used near the face, and a permanent turnout was advantageously installed at the halfway point of the tunnel.

The cars were the same as those used on the main mine haulage; namely, 40 cubic foot rocker dump, 8 feet 8 inches long by 3 feet 4 inches wide, with a height above rail of 4 feet 7 inches. Each car weighed 2,500 pounds, was mounted on 4 wheels of 14 inches diameter, and equipped with Hyatt roller bearings.

A Titan B,  $2\frac{1}{2}$ -ton Mancha locomotive with battery, 7 feet 8 inches length overall with a chassis width of 38 inches was used. This locomotive had a turning clearance length of 6 feet 7 inches, wheel base of  $25\frac{1}{2}$  inches, wheels of 16 inches diameter, diameter of axles  $2\frac{1}{8}$  inches, and the transmission was of gear type. There were two sets of Philadelphia batteries, 25 cells each, type 23 plates, with a rated discharge capacity per set of 330 ampere hours and 16.2 kw.h. An a.c. to d.c. motor-generator set with motor to operate on 440 volts, 3-phase, 60-cycle current, 4 kw.h., was used to charge the batteries; this was equipped with automatic charging panel.

On the outside of the tunnel there was a slight depression which was taken advantage of to start the waste dump, which was built up in a fan-shaped pile, moving the track to the outer edge whenever needed.

#### GROUND SUPPORT

With the exception of a little timber used at and near the portal of the tunnel, the ground required no support.

## VENTILATION

Ventilation was effected by an electric-driven No. 7 Connersville positive blower, exhausting through a 16-inch galvanized-iron pipe. The method of joining the pipe was to bell out slightly one end and force the succeeding pipe into it. The joint was then wrapped with cotton cloth dipped in crude oil and was bound and belted by a galvanized-iron strap which was drawn up with quarter-inch bolts. The ventilation line was carried in an upper corner of the tunnel and was hung with wire from wooden plugs driven into short vertical holes. The blower was equipped with connections for reversing the direction of the air, but best results were obtained by continuous exhausting.

## BLASTING

The shift boss fired all holes. Forty per cent gelatin dynamite was used, the size of cartridge being  $1\frac{1}{4}$  by 8 inches. The cartridges were exploded by No. 8 detonators using Sylvanite fuse. The primers were prepared outside the portal and brought to the working face on the haulage motor which also brought the powder. The usual position of the primer was the third cartridge from the bottom of the hole. No stemming was used.

## Cycle of Operations

Beginning with a clean set-up, the power shovel was pulled back to the passing switch and the drill carriage was pushed to the face. Each of the four machines had a prescribed number of holes to drill and during the drilling time the shovel runner overhauled and oiled the shovel and the track crew cleaned up along the side to prepare for laying track and pipe.

After the drilling was completed the motor pulled the drill carriage back to the portable turnout and the drill crew blasted the round. After waiting 10 minutes after the last shot exploded, about 1,000 feet back from the face the entire crew took shovels and cleaned up the track to the point at which the muck pile was about a foot high. The shovel followed the crew and necessary connections were made when the muck pile was reached.

Three men pushed one 40 cubic foot car from a group of six empties from the portable turnout switch to the shovel, after which another empty was placed on the passing switch to be exchanged as soon as the first was filled (fig. 6). Loaded cars were returned to the loaded side of the portable turnout and then taken outside by the haulage motor as soon as a train was completed. Empties were kept on the opposite side of the portable turnout switch.

Considerable time was saved by keeping the passing switch within 150 feet of the face, and when the distance between the turnout and passing switches became so great that an empty could not be returned to the passing switch while the mechanical shovel was filling a car, the turnout switch was moved ahead.

While loading was in progress, one of the machine men and the drill-carriage boss inspected the drills, replaced dull with sharp steel, filled the oilers and prepared for drilling the next round.

Following is a tabulation showing the time consumed in the various operations:

Time consumed by various operations

|                                                          | Average Cycle |         | Best Cycle |         |
|----------------------------------------------------------|---------------|---------|------------|---------|
|                                                          | Hours         | Minutes | Hours      | Minutes |
| Delivery of drill carriage to face and setting up        | 0             | 30      | 0          | 15      |
| Total drilling time                                      | 1             | 50      | 0          | 55      |
| Tearing down, blowing, loading holes, and blasting       | 0             | 35      | 0          | 25      |
| Waiting for smoke                                        | 0             | 12      | 0          | 5       |
| Cleaning up ahead of shovel                              | 0             | 15      | 0          | 7       |
| Loading (average of twenty 40 cubic foot cars per round) | 2             | 0       | 1          | 45      |
| Interval between (loading completed and set-up started)  | 0             | 15      | 0          | 7       |
| Total time                                               | 5             | 37      | 3          | 39      |

Table 1.- Personnel

|                                           | Number per shift | Number of shifts | Total per 24 hours |
|-------------------------------------------|------------------|------------------|--------------------|
| 1. Supervision and loading <sup>1</sup>   | 1                | 3                | 3                  |
| 2. Drilling and blasting                  | 10               | 3                | 30                 |
| 3. Haulage                                | 8                | 3                | 24                 |
| 4. Timbering                              | 0                | 0                | 0                  |
| 5. Rock disposal                          | 2                | 3                | 6                  |
| 6. Steel shop                             | 3                | 1                | 3                  |
| 7. Surface plant, exclusive of steel shop | 2                | 3                | 6                  |
| 8. Miscellaneous                          | 20               | 1                | 20                 |
| Total                                     | -                | -                | 92                 |

1 Shift boss was also operator of mechanical shovel loader.

Table 2.- Cost per foot in dollars, U. S. currency (For 5,405 feet of tunnel)

|                          | Labor and super-vision | Comp. air drills, steel, etc. | Power | Explo-sives | Timber and concrete materials | Other supplies | Total  |
|--------------------------|------------------------|-------------------------------|-------|-------------|-------------------------------|----------------|--------|
|                          | 1                      | 2                             | 3     | 4           | 5                             | 6              | 7      |
| A. Drilling and blasting | \$3.99                 | -                             | -     | -           | -                             | -              | -      |
| B. Loading               | 1.55                   | -                             | -     | -           | -                             | -              | -      |
| C. Haulage               | 1.44                   | -                             | -     | -           | -                             | -              | -      |
| D. Timbering             | -                      | -                             | -     | -           | -                             | -              | -      |
| E. Concreting            | -                      | -                             | -     | -           | -                             | -              | -      |
| F. Rock disposal         | .32                    | -                             | -     | -           | -                             | -              | -      |
| G. Drainage              | -                      | -                             | -     | -           | -                             | -              | -      |
| H. Ventilation           | .36                    | -                             | -     | -           | -                             | -              | -      |
| I. General               | 2.67                   | -                             | -     | -           | -                             | -              | -      |
| Totals                   | 10.33                  | 3.48                          | 0.84  | 3.77        | 0.00                          | 2.945          | 21.365 |

Note: Construction and equipment, not included above costs per foot \$11.92.

Table 3.- Costs per foot of tunnel in units of labor, power, and supplies


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Period covered: 210 days.

## A. Labor, man-hours per foot:

|                                     |             |
|-------------------------------------|-------------|
| 1. Breaking (drilling and blasting) | 9.32        |
| 2. Loading                          | .90         |
| 3. Haulage                          | 7.45        |
| 4. Rock disposal                    | 1.86        |
| 5. Ventilation                      | 1.24        |
| 6. Miscellaneous                    | <u>7.79</u> |

Total man-hours per foot of tunnel 28.56

## B. Power and supplies (estimated):

Kw.h. per foot of tunnel

|                        |                 |
|------------------------|-----------------|
| 1. Air compression )   |                 |
| 2. Mechanical loading) | 88.7            |
| 3. Haulage             | 2.6             |
| 4. Lighting            | 1.0             |
| 5. Ventilation         | 39.9            |
| 6. Pumping             |                 |
| 7. Miscellaneous       | <u>        </u> |

Total kw.h. per foot of tunnel 132.2

Explosives, pounds per foot of tunnel,

kind and grade 40 per cent gelatin 22.7

Timber, b.m. per foot of tunnel

None

Lagging, per foot of tunnel (size and length)

None

Steel consumption per foot of tunnel

2.9 pounds

Cubic feet compressed air per foot of tunnel

44,320

Other supplies in per cent of total power and supplies

26.6

Labor, per cent of total cost

48.35

Power, per cent of total cost<sup>1</sup>

3.95

Supplies, per cent of total cost

47.70


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1 Does not include power for compressor.

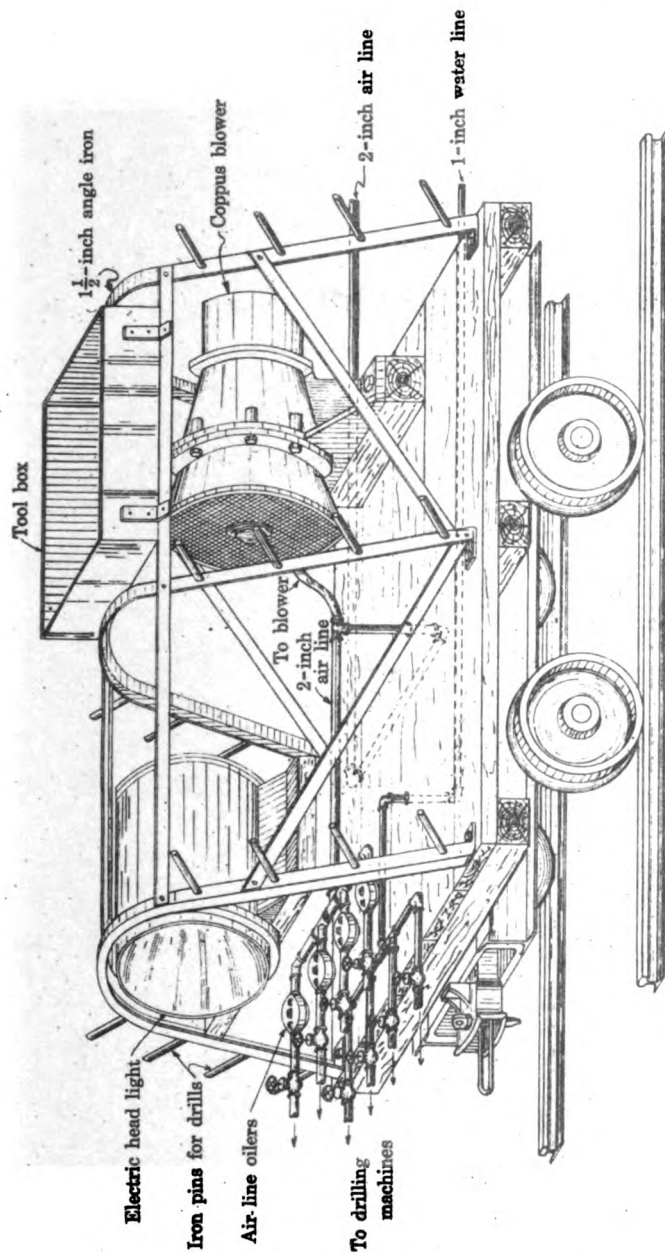


Figure 5.—Hezelwood drill tender

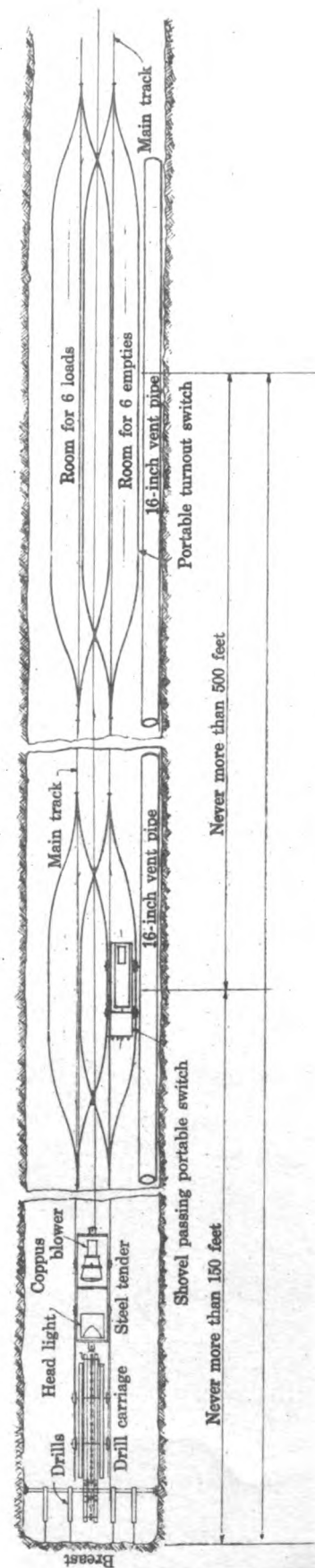


Figure 6.—Arrangement of switches